The Low Density Supersonic Decelerator (LDSD) project’s purpose is to test three designs in Mars-like environments: Two Supersonic Inflatable Aerodynamic Decelerators (SIAD), the SIAD-R and the SIAD-E; and the Supersonic Disk Sail (SSDS) parachute. The SIAD-R is meant for Robotic Class Missions, allowing larger robots or rovers to be sent to Mars with more precise landings. The SIAD-E is meant for Exploration Class Missions, the end goal for this SIAD is to make it possible for humans to settle on Mars. The differences between the two SIADs are the size and shape of the SIADs. The purpose of the SIADs is to increase surface area without increasing weight or mass; this creates more drag and therefore deceleration. Refer to figure 1 to see the physical differences between the SIADs. The SSDS is the biggest parachute of its kind and has a unique design. Both the SSDS and the SIAD-R designs have been in full-scale testing prior to the launch at the Pacific Missile Range Facility (PMRF) Barking Sands Kaua‘i Hawai‘i. The LDSD project will occur in Earth’s upper atmosphere, where the air is less dense and better simulates Mars’ atmosphere.
INTRODUCTION

LDSD plans on expanding and improving on the Viking Balloon Launched Decelerator Test (BLDT). The Viking BLDT occurred in the summer of 1972 at White Sands Missile Range in New Mexico. The Viking BLDT tested the Viking Disk-Gap-Band (DGB) parachute in Mars-like conditions. The LDSD test is modeled after the Viking BLDT in many ways: using a weather balloon to achieve the desired altitudes, the SSDS is a larger version of the DGB, and the Viking BLDT used onboard rocket motors to achieve the supersonic speeds needed to conduct the test.

METHOD

NASA went through a selection process to find the range facility that would best host the LDSD project. Three ranges were considered: US Navy San Nicolas Island off California, Royal Australian Air Force Woomera Test Range, and the US Navy Pacific Missile Range Facility (PMRF). These ranges were rated on several qualities including range services and instrumentation, conditions for balloon launch, conditions for balloon trajectory and ascent, and range availability. Other factors were taken into account but those were more or less the main qualities desired. PMRF was chosen because it rated best in most categories followed by Woomera. Referring to figure 2, the three ranges were rated from one to three, three being the best out of the three choices. The ratings were summed up and the range with the highest total was probably the best choice.

<table>
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<th>Criteria</th>
<th>San Nicolas</th>
<th>PMRF</th>
<th>Woomera</th>
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<tr>
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Figure 2: Range Selection Results

The LDSD project requires collaboration between many facilities such as NASA Wallops Flight Facility (WFF) in Virginia, NASA Jet Propulsion Laboratory (JPL) in California, NASA Columbia Scientific Balloon Facility (CSBF) in Texas, and PMRF at Barking Sands Kaua‘i, Hawai‘i. JPL made the Test Vehicle (TV); they are in charge of the maintenance and the operation of the TV. CSBF is responsible for the balloon and all of its components; they are also responsible for keeping track of the weather and providing weather data for the balloon trajectory predictions. WFF is in charge of the overall operations on the LDSD project side; Shad Combs, who is from WFF, was in charge of Range Coordination with PMRF. PMRF is in charge of hosting the project and providing the required instrumentation and telemetry for the project. PMRF is also in charge of maintaining safety guidelines for the island of Kaua‘i; PMRF Range Safety had to approve the project before the project could occur and Range Safety has the authority to stop the project at any time during the project if they deem the project unsafe or if the project endangers any civilians or personnel in the area.
The interns’ job in the LDSD project was to compile all of the essential checklists and documents for launch day into a Launch Book. Some documents included in the book were the LDSD Master Countdown, Test Conductor’s Checklist, and Launch Constraint Documents. These were some of the documents that the LDSD personnel needed on-hand during the mission for quick reference. These launch books were made primarily for the LDSD personnel in the PMRF Range Operations Control Center (ROCC) also known as building 105. The ROCC is a high security area that does not allow phones or laptops, having electronic versions of the essential documents were not possible. Having physical hard-copies was the only way for those in the ROCC to have the documents necessary for launch.

The balloon trajectory predictions were acquired and calculated depending on the weather as the scheduled launch window was closing in. Trajectory predictions were acquired using a method called the Monte Carlo method. The Monte Carlo method in the LDSD test was implemented by simulating the balloon trajectory many times using the weather data for that day and with slight variations through each simulation. The simulations are done through a MATLAB program that takes weather data, and other variables, as parameters. The simulation is done about 8,000 times and trends are revealed as certain paths are projected more frequently. A path that best fits the trending path predictions is derived from the collected data and that is presented as the predicted balloon trajectory for that particular day.

Once the predicted trajectory for the planned window was discussed and approved by the LDSD team and range safety, balloon preparations were made and the TV was suspended on the launch tower’s arm, as shown in figure 3. The balloon takes some time to fill up for it requires about 250,000 cubic feet of helium. The balloon used for the LDSD test is known as the 34 Heavy (34H) because it has a volume of about 34 million cubic feet. Once the balloon is filled, the balloon was released and it takes the suspended TV off of the launch tower’s arm. Once the balloon with the TV was up in the air away from the launch tower, it was at the mercy of the winds. There was about a two hour ascent time before the balloon and TV arrived at the desired 120,000 feet altitude. The balloon ascent is the most unpredictable part of the test because the winds are unpredictable. If the balloon were to drift into a restricted or unsafe zone where people were put in danger, range safety had the power to ‘pull the plug’ on the tests and abort procedures would initiate. In the unfortunate event that something like that would happen mid-ascent, the balloon can self-terminate.

Once the balloon and TV hit an altitude of about 120,000 feet, the TV detached from the balloon and a couple of events occurred instantaneously. The TV has spin motors that was used to induce spin on the TV; this provided stability to the TV as it used its main motor, the Star48, to get up to just under Mach 4 speeds and reach a higher altitude of about 180,000 feet.
balloon self-terminated a couple of seconds after the TV drop and fell into the Pacific where it was recovered. Once the desired speed was reached, spin motors pointing the opposite way of rotation were used to stop the rotation.

The LDSD test began once the TV is moving at about Mach 4 at an altitude of about 180,000 feet. First, the SIAD was deployed; in this case, the SIAD-R was used for the initial deceleration. The SSDS was then deployed when the TV slowed down to a velocity of about Mach 2. The SIAD worked wonderfully, but the SSDS ripped upon deployment. The SSDS parachute ripped open as soon as it was deployed so it failed. Figure 4 is a timeline of the whole flight from balloon launch to the TV recovery.

RESULTS

The SSDS parachute failed but the test was a great success. Everything worked wonderfully from the balloon launch to the recovery of the balloon and TV. Everything was recovered by the Kahana, a local boat from Port Allen Kaua‘i, and taken back to Port Allen, where it was then transported back to PMRF for processing and analysis. The TV was intact and the balloon carcass was recovered. The parachute was tied in many knots and was heavily tangled as shown in figure 5. Everything was shipped back to JPL for further analysis. The on-board GoPros, high-definition, and high-speed cameras were also recovered. The GoPros provided great footage of the flight and provided some hints as to what exactly happened to the SSDS. The high-definition and high-speed camera footage will be used to do a more in-depth analysis of the SSDS failure.
The LDSD project faced some problems at PMRF. LDSD is the first project in history to launch a rocket off of a weather balloon in this way so there were many unknowns going into the project. Because the balloon was at the mercy of the weather, it was impossible to predict the exact trajectory of the balloon. This randomness via the weather created many uncertainties, which PMRF flight safety was somewhat comfortable with. The predicted projections were broad and the restrictions were strict; if the weather wasn’t perfect, there was always the possibility that the balloon would float into restricted areas and air space. This almost caused the cancelation of the LDSD project because the weather did not cooperate for the scheduled launch window. LDSD luckily got a second chance by returning at the end of June 2014 for a small extension. Eventually, the wind directions moved in such a way that the balloon trajectory was almost guaranteed to not move into off-limits areas. The LDSD team jumped on the opportunity and proceeded to mission success on June 26.

CONCLUSION

NASA LDSD plans to come back to PMRF next year in the summer of 2015. NASA JPL plans to make two test vehicles with improved SIAD and SSDS designs. It is still undecided yet if the SIAD-E will make it to the tests next year due to lack of testing and uncertainty. The SSDS design will be analyzed and improved according to what problems caused the SSDS to rip and fail.

The LDSD team hopes to use these designs on real Mars landers or rovers in the future. Landing Humans on Mars will hopefully be obtainable using the SIAD-E. Bigger rovers and payloads can be sent to mars using the SIAD-R.

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